Dealing with Historical Discrepancies: The Recovery of National Research Experiment (NRX) Reactor Fuel Rods at Chalk River Laboratories (CRL) – 13324

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ABSTRACT

Following the 1952 National Research Experiment (NRX) Reactor accident, fuel rods which had short irradiation histories were "temporarily" buried in wooden boxes at the "disposal grounds" during the cleanup effort. The Nuclear Legacy Liabilities Program (NLLP), funded by Natural Resources Canada (NRCan), strategically retrieves legacy waste and restores lands affected by Atomic Energy of Canada Limited (AECL) early operations. Thus under this program the recovery of still buried NRX reactor fuel rods and their relocation to modern fuel storage was identified as a priority. A suspect inventory of NRX fuels was compiled from historical records and various research activities. Site characterization in 2005 verified the physical location of the fuel rods and determined the wooden boxes they were buried in had degraded such that the fuel rods were in direct contact with the soil. The fuel rods were recovered and transferred to a modern fuel storage facility in 2007. Recovered identification tags and measured radiation fields were used to identify the inventory of these fuels. During the retrieval activity, a discrepancy was discovered between the anticipated number of fuel rods and the number found during the retrieval. A total of 32 fuel rods and cans of cut end pieces were recovered from the specified site, which was greater than the anticipated 19 fuel rods and cans. This discovery delayed the completion of the project, increased the associated costs, and required more than anticipated storage space in the modern fuel storage facility.

A number of lessons learned were identified following completion of this project, the most significant of which was the potential for discrepancies within the historical records. Historical discrepancies are more likely to be resolved by comprehensive historical record searches and site characterizations. It was also recommended that a complete review of the wastes generated, and the total affected lands as a result of this historic 1952 NRX accident be undertaken. These lessons and recommendations have lead to changes in how the NLLP is executed in the CRL waste management areas.

INTRODUCTION

The Nuclear Legacy Liabilities Program (NLLP), funded by Natural Resources Canada (NRCan), strategically retrieves legacy waste and restores lands affected by Atomic Energy of Canada Limited's (AECL) early operations [1]. The Environmental Remediation and Technical Support (ERTS) Branch at Chalk River Laboratories (CRL) is responsible for facilitating many of the initiatives of the NLLP at CRL. Among these initiatives is the investigation of waste inventory in the CRL waste management areas (historically referred to as "disposal grounds"). Along with buried liquid wastes, fuels buried outside of any containment were identified as a priority for assessment. Practices for long-term fuel storage have evolved and can provide more robust engineered containment; thus improving safeguards for nuclear fuel and minimizing the risk of contaminant migration into the environment. Thus a retrieval project was undertaken to address the historic burial known on disposal drawings as: *"Wood Box, angled north. End clear* *of grade – contains pieces of rods from Fuel Rod Bays - Sept – Oct/53"* and *"Split Rod, Sept/53"*.

Background

On December 12, 1952, the National Research Experimental (NRX) reactor core at CRL experienced a partial meltdown [2]. The power in the NRX reactor abruptly and uncontrollably increased to ~90 MW. Fuel rods that were in the calandria received inadequate cooling for high power operation, which caused several fuel rods to rupture and melt. Fuel channels were badly damaged including the fusing of fuel rods to the aluminium calandria tubes, which held the fuel rods in place in the reactor. At the time of the accident, several experimental fuel rods were also present in the calandria.

Following the accident, refurbishment activities included removal of fuel rods from the reactor and discarding the calandria. The calandria, which still contained portions of fuel rods melted in position, was transferred to the CRL disposal area. Fuel rods, which had been successfully removed from the calandria tubes, were placed in the Fuel Rod Bays. This event was one of the first serious reactor accidents in the world, and presented unique research opportunities. The fuel rods were cut-up and distributed to various research groups, both onsite at CRL and offsite.

Following the completion of the reactor restoration, the Fuel Rod Bays themselves underwent a period of cleanup and refurbishment. Any fuel rods with recoverable plutonium were sent to the fuel extraction branch (Chemical Operations Branch) at CRL. Since high aluminium content adversely affects the extraction process, the threaded aluminium end pieces were cut off and discarded. Other fuel rods, which experienced little to no irradiation, were candidates for disposal. The fuel rods that were removed from the Fuel Rod Bays included: natural uranium fuels with low plutonium content, intact or pieces of sample rods, and cut ends of fuel rods. Historical records indicate that the fuel rods and/or cans were placed in a wooden box and sent to the CRL disposal area for "temporary storage". Historical records report that a large wooden box, approximately 4.4 m long by 0.7 m high and 0.9 m wide was buried in the sand at a 30 degree angle. This box can be seen in a photograph of the "disposal grounds" taken in 1957 June. Fig. 1 shows the box protruding above the ground surface. The wooden packaging would have degraded over time and was likely failing to provide proper containment of the fuel rods. The objective of the 2007 retrieval project was to recover the fuel rods and cans buried as inventory at the "Wood Box" and "Split Rod" burial site, place them into modern fuel packaging, and transfer to a secure, modern fuel storage facility.

DESCRIPTION

Site Characterization

The assessment of the "Wood Box" and "Split Rod" burial began with reviewing the historical records followed by field characterization activities to locate and visually examine the inventory.

The historical assessment was initiated in early 2005 with a review of available records from Waste Management files, Nuclear Material and Safeguards inventory and central records, and included:

- Reports of the cleanup efforts following the NRX accident,

- Available waste disposal slips,
- Fissionable and Fertile Gain/Loss Reports
- Rod Assembly Irradiation and Storage Cards, and
- Archived photographs.

Fig.1 The "disposal grounds" in 1957, showing the "Wood Box" protruding above grade.

The records search revealed a disposal slip which provided the exact location of the "Wood Box" relative to the fence line that had existed in 1953. It also mentioned four discrete shipments that consisted of 13 fuel rods in total. The disposal slip also listed five subsequent shipments but did not explicitly state the number of fuel rods associated with them. The search of the fissionable and fertile Gain/Loss reports listed a total of thirteen fuel rods and cans that were sent out to the "disposal grounds". The content indicated on the Gain/Loss report (X) was fuels comprised of natural uranium metal fuel with very low plutonium thus indicating a very short irradiation. A search of records for Rod Assembly Irradiation and Storage cards resulted in locating cards for only two rods (#9770 and #5708). Rod #9770 had been cut into several sample pieces for further research. Rod #5708 had been damaged during retrieval from the calandria and it was anticipated parts of the fuel rod may have still been in the calandria tube. A Rehabilitation Report for the Fuel Rod Bays produced in 1954 listed an inventory that had been shipped to the "disposal grounds". Thus Fig. 2 represents the suspect inventory for the "Wood Box" burial which was derived from this 1954 Rehabilitation Report (written after the cleanup). The Gain/Loss report (X), however, indicated two extra fuel rods which were not listed in the 1954 reported inventory, including: Cook's N Cooled Rod P.I.R #3802 and Lavigne's Flat Bar Rod P.I.R #2549. It was expected that this two rod discrepancy would be resolved with further examination of the records or during identification of the fuel rods in the field.

Item and Description	Approx. U Content kg.	Approx. Pu Content g.	Identification
1. U.K. Slug Rod #2052			A mild steel collar was slipped over the rod and tightened to it with a locking bolt. The rod number is stamped on the collar. A plastic covered wire fixed to the collar runs out of the box and is tied to a nail rack, where it has an aluminum tag fixed to it. The number is also on this tag.
2. U.K. Stability Rod #5 (F.I.R. R-1160)			"
3. U.K. Stability Rod (F.I.R. #3913)			"
4. Cook's trans. Rod #2 (F.I.R. #3305)			"
5. Cook's trans. Rod #3 (Dwg. 1255-B)			"
6. Lavigne's Flat Bar Rod (F.I.R. #3394)			"
7. Lavigne's Flat Bar Rod (Dwg. 1115-A)			"
8. U.S. Stab. Rod #1 (Dwg. #1369-A")			"
9. The following X-rods (damaged during pile accident and received 0 irradiation) 7969-X, 9770, 5712, 5706, 5619, 5538			An aluminum tag was wired to each rod. All rods were then crated into a box 10" x 12" x 12 ft. The crate containing the rods was stored in the box at the disposal ground.
10. Flats from N.R.U. Loop #1			Flats D-362, G-1852, D-913 and D-370 were bundled together and tagged. Flat D-373 is canned and it is tagged in the same manner as items #1 to #9.
11. Seven cans of end pieces from X-Rods 500 651 675 661 665 690 399 417 358 430 591 582 593 594 451 362 387 691 459 543			No identification. Pieces are sufficiently inactive to permit examination of bottom plug for positive identification.

Fig. 2 Historically reported inventory of Wood Box as taken from the 1954 Rehabilitation Report.[1]

In addition to the "Wood Box" burial it was also anticipated that a "Split Rod" was buried at the same location. However the identity of the "Split Rod" was uncertain. One possible candidate was X-rod[1] 8849. This fuel rod was reportedly damaged and sent for "temporary storage" in the "disposal grounds". A loss of natural uranium fuel was recorded in Gain/Loss report (Y); however a later Gain/Loss report (Z) indicated a recovery of natural uranium fuel, after retrieval and de-sheathing. It was presumed that the remainder of the fuel rod was left in place at the "disposal grounds".

Following the records review, field characterization activities were performed in 2005 with the objective to obtain the following information:

- The location of the "Wood Box" and "Split Rod",
- The physical configuration of the "Wood Box" and "Split Rod" (e.g. nature and condition of any containers, how many fuel rods or cans, and what types of fuel rods),
- The radiological condition of the "Wood Box" and "Split Rod", and
- Contamination survey of surrounding soil.

The scope of fieldwork included manual excavation to partially expose portions of the suspect burial area. The inventory was located as per description on the disposal slip. The north end of the burial was only 0.6 m below grade however further to the south the burial was 1.8 m below

[1] The term "X-rod" was used to denote a natural uranium that was typically used in the NRX Reactor.

grade, confirming the fuel rods and cans were buried on an angle. Several photographs were taken as records including Fig. 3. As indicated in Fig. 3, fuel rods, some in aluminium cans, were buried in the sand with no other apparent containment. From the safe inspection distance, no identifying marks could be seen on the ends of the fuel rods and cans or their steel collars. Most of the fuel rods appeared to be contained in aluminium cans or flow tubes, with either crimped or welded ends. One fuel rod was not canned and had been stripped of its flow tube, exposing the fuel sheath which had obviously been cut during post accident examinations. Fig. 4 shows the visually evident uranium corrosion. The sheath cooling fin design identified this fuel rod as an NRX X-rod. Also visually evident was confirmation that some fuel rods had been broken off inside a calandria tube as shown in Fig. 5. This is consistent with operational records (i.e. 1954 Rehabilitation Report) and the description of Rod #5708 handling.

Fig. 3 Characterization activities in 2005 reveal the fuel rods. While several of the fuel rods or can had collars with identification tags, some fuel rods or cans were unmarked.

Rotted wood indicated the presence of what had been the original wood box containing the rods. Identification tags provided confirmation of several fuel rods listed in the suspect inventory. In total eight tags were observed to confirm the suspect inventory (as in Fig. 2) including: 430 Cut Ends, 651 Cut Ends, 476 Cut Ends, 7 Slugs from U.K. Rod #2052, Lavigne's Flat Bar Rod #3394, Canned Flat D373, U.K. Stability Rod #5, U.S. Stability Rod. During this characterization activity, discrepancies from the suspect inventory were already obvious as the inventory presented in Fig. 2 did not include an entry for "476 Cut Ends".

General gamma radiation fields varied from 3 mSv/hr to 650 mSv/hr at near contact distances. Since the fuel rods and cans were in close proximity to each other, the measurements were resultant of a collective rate. For hazard reference purposes, a soil grab sample was sent for analyses and exhibited low levels of contamination (*i.e.* 2 cpm alpha with a Ludlum 43-5 detector and 1,000 cpm beta/gamma with a Ludlum 44-9 detector).

Fig. 4 An uncanned NRX X-rod which had been stripped of its flow tube, exposing the fuel sheath. Uranium corrosion is visually evident with the yellow product present.

Fig. 5 A canned fuel rod that had been broken off inside a calandria tube.

Assessment and Planning

Based on the deteriorated condition of the fuel rods' containment observed during the site characterization, a recommendation for the retrieval of the "Wood Box" contents and "Split Rod" was made. Documents detailing the proposed retrieval operation were prepared in conjunction with reports assessing the hazards and appropriate mitigations with respect to Health Safety and Environment (HS&E) risks (i.e. dose assessments and environmental evaluations). The concept for the retrieval and transfer of the fuel rods involved:

- Excavation to expose the "Wood Box" and "Split Rod",
- Transfer of the fuel rods to a rigid support angle iron,
- Transfer of the fuel rods into modern fuel cans,
- Placement of the modern fuel cans into an onsite shipping box,
- Transport of the shipping box to a modern storage facility,
- Removal of contaminated soil from the excavation site, and
- Backfilling of the excavation site.

The planned inventory verification involved using only field methods such as recovered identification tags, radiation field measurements and visual observations.

Several mock-ups were performed in anticipation of fieldwork commencing after receiving the necessary approvals. The purpose of the mock-ups was to ensure the retrieval operations were effective, identify potential issues, and develop alternative techniques if necessary. The staging also ensured the tooling manufactured for the retrieval was adequate and personnel involved were appropriately trained. The retrieval and transfer was coordinated with AECL's Nuclear Materials and Safeguards Program who arranged for the oversight of safeguards inspectors from the International Atomic Energy Agency (IAEA) and Canadian Nuclear Safety Commission (CNSC).

Execution of the Retrieval

The retrieval of the inventory within the "Wood Box" and "Split Rod" burial and transfer to a modern fuel storage facility was executed in the Fall of 2007. Due to the primitive conditions of the "Wood Box" and "Split Rod" burial, the design of the retrieval was relatively simplistic. The process involved burying new fuel cans on an opposite angle to the legacy burial. The buried fuel rods and cans were then systematically and carefully exposed and rolled onto an angle iron using remote tooling. As shown in Fig. 6, the angle iron was then hoisted to the mouth of the new fuel cans and angled such that the fuel rod or can would slide into the new packaging.

Fig. 6 Retrieval of the fuel rods and loading into new modern fuel cans with remote tooling and the angle iron.

Fuel rod identification was made possible by recording the information on any recovered identification tags which were attached to the collar on the fuel rod or can. An inventory of the recovered fuel rods or cans was maintained throughout the retrieval. Radiation fields were recorded once the fuel rod or can was on the rigid support angle iron, and identification tags and collars were removed. The collars impeded the emplacement of the fuel rods into the awaiting fuel cans. From the suspect inventory from the 1954 Rehabilitation Report presented in Fig. 2, items 1 through 8 and item 10 were positively identified as recovered using recovered identification tags. Some cans as identified in item 11 of Fig. 2 were also recovered with tag identification. When identification was not possible, either the tag was broken off or there was no identification attached, these fuel rods or cans were recorded as “Unidentified Fuel Rod” with a corresponding physical assessment (radiation measurements and qualitative description) as noted in Table I.

The original assessment of the “Wood Box” inventory had indicated 19 fuel rods and cans present, including the “Split Rod” adjacent to the “Wood Box”. As shown in Table I, a total of 32 fuel rods, cans and pieces were recovered and transferred to the modern storage facility. Although the expected number of fuel rods and pieces to be recovered at this burial site always carried some uncertainty, this large discrepancy was unexpected. The number of modern fuel cans available for packaging the total inventory was insufficient. Thus the retrieval operation was postponed for a couple of weeks until additional fuel cans were secured. Meanwhile the site was placed in a secured state. This included emplacement of safeguard security seals on the fuel cans containing retrieved fuel rods and leaving all remaining fuel rods buried. The fuel rods and cans with cut ends identified as being recovered by the completion of this project included:

- Seven anticipated cans of cut end pieces;

- Thirteen (to fifteen)[2] extra cans of cut end pieces (12 cans and 7 pieces of fuel rod); and
- Nine sample or experimental fuel rods.

Remnants of the wood packaging were found during the retrieval operation; however, the amount of deterioration made distinction between the “Wood Box” containing the Fuel Rod Bay rod sections and “Split Rod” box impossible.

Radiological contamination was measured in the field with a Ludlum M12 44-9 beta/gamma contamination meter and a Ludlum M12 43-5 alpha contamination meter. Radiation fields were measured using a BOT P200 gamma survey meter. Background readings of the general area prior to excavation were 300 cpm beta/gamma and < 0.01 mSv/hr gamma radiation fields. A number of simple precautions were taken to keep the collective doses as low as possible during the retrieval operation. This included burying the new fuel cans in the sand during the retrieval operations and using nuclear operators who were trained in the proper use of remote tooling. The radiation fields recorded for each recovered fuel rod/can is presented in Table I. The highest gamma radiation field observed during the retrieval operations was 85 mSv/hr and represented a collective rate measurement on several exposed fuel rods still within the ground. The collective dose for all workers during the entire execution of activities was 2.73 mSv, which was below the target collective dose of 3 mSv. This was a significant achievement considering the unanticipated extra inventory and the time spent in the field performing the retrieval operation was double the amount originally expected.

Site Closure

Since the location of the burial was within a licensed waste management area, with other legacy wastes and extensive soil contamination, ongoing operational restrictions for this site would continue past this specific retrieval operation. As such the removal of contaminated soil was only completed to the extent that facilitated the removal of the targeted burial. The excavation and segregation of re-usable and contaminated soil was performed utilizing the above described radiological field instrumentation. Any impacted soil with concentrations below an operational threshold criterion was used as fill for the excavation. Contaminated soil was removed and placed into lined non-compactable bins and placed into CRL’s Low Level Waste storage facility.

Following the removal of the legacy inventory and contaminated soil, the gamma radiation fields within the excavation measured < 0.01 mSv/hr. The excavation was backfilled, topsoil emplaced and site seeded. A final radiological survey was conducted, which included all areas impacted by the activities involved in the retrieval project. At the time of the final survey, the general area reported background levels (300 cpm beta/gamma with a Ludlum 44-9).

[2] The reference source discusses the potential for thirteen to fifteen cans *will be shipped* to the “disposal grounds”, thus the actual number of cans was not conclusive in the original records.

Table I. Inventory of recovered fuel rods and cut ends. (NOTE: **Indicates where an identity has been assigned.)

Recovered Fuel Rod or Cut Ends	Field Observations	Radiation Field Gamma @ contact
1. Unidentified fuel Rod		4.5 mSv/hr
2. 430 Cut Ends		12 mSv/hr
3. Unidentified Fuel Rod		4.5 mSv/hr
4. **Unidentified Fuel Rod – assigned identity of Lavigne's flat bar rod 2549 due to fields and weight during recovery	Collar attached but no wire or ID tag	26 mSv/hr
5. 7 Slugs from UK rods 2052		22 mSv/hr
6. **Unidentified Fuel Rod - assigned identity of Cooke's N Cooled Rod 3802	Only 1 m long	20 mSv/hr
7. 591 Cut Ends		1.65 mSv/hr
8. UK Stability Rod 3913		22 mSv/hr
9. **Unidentified Fuel Rod - assigned identity as UK Stability Rod #5 based on fields and proximity to other UK Stability Rod	Collar attached but no wire or ID tag	23 mSv/hr
10. Unidentified Fuel Rod		5.4 mSv/hr
11. Canned Flats D373		5 mSv/hr
12. **Unidentified Flat Bars - suspect to be Lavigne's Flat Bar Rod (Dwg 1115-A) but no tag recovered for positive ID	Several of flat bars bundled together	5.5 mSv/hr
13. Unidentified Fuel Rod	Cap and wire still attached but no ID tag	15 mSv/hr
14. Unidentified Fuel Rod		15 mSv/hr
15. Unidentified Fuel Rod		8.5 mSv/hr
16. Flats from NRU loop - D362, G1852, B943, F370 bundled together in can	Full of pit marks, corroded	55 mSv/hr
17. Unidentified Fuel Rod		5 mSv/hr
18. 6 Cut End Pieces		0.5-1 mSv/hr each
1 Cut End Piece		1.3 mSv/hr
19. 651 Cut End Pieces from J Rods		45 mSv/hr
20. Cooke's Transformer #2, 3805		33 mSv/hr
21. Lavigne's Flat Bar Rod, PIR 3394		4.75 mSv/hr
22. Cooke's Transformer #3, Dwg. 1255-B		21 mSv/hr
23. Unidentified Fuel Rod		1.3 mSv/hr
24. Unidentified Fuel Rod		9.5 mSv/hr
25. 358 Cut Ends		15 mSv/hr
26. US Stability Rod #1		33 mSv/hr
27. Unidentified Fuel Rod	Slightly bent	5.5 mSv/hr
28. Unidentified Fuel Rod		8.5 mSv/hr
29. Unidentified Fuel Rod		5 mSv/hr
30. Unidentified Fuel Rod		4.6 mSv/hr
31. Unidentified Fuel Rod		6.8 mSv/hr
32. Unidentified Fuel Rod		4.4 mSv/hr

DISCUSSION

A significant lesson learned from this retrieval was the potential for significant discrepancies between historical records. In many cases when dealing with historical discrepancies, verification cannot be achieved until the inventory is retrieved. The discovery of the unanticipated fuel rods and cans delayed the completion of the project, increased the associated costs, and required more than anticipated waste storage in the modern fuel storage facility. Following the completion of the field activities in the Fall of 2007, considerable effort was made to rectify the inventory and disposition the discrepancies. This included a supplemental historical review of records. Part of the follow-up included a review of the weekly reports for the AECL division which was responsible for the cleanup following the NRX accident. Within these weekly reports were limited discussions on the management of wastes generated during the clean up activities including the disposition the fuel rods involved in the accident.

Table II provides a summary of the literature review revealing several burials of fuel rods in the disposal area, which were not accounted for previously. In a cleanup progress report from August 21 to October 8 1953, a rod storage box was buried in the disposal area for storing material having received little irradiation. Thirteen (to fifteen cans), containing cut ends sheared from X-rods, were stored in this box. These cans of cut ends were not accounted for in the original suspect inventory discussed in the 2005 historical assessment, or the 1954 Rehabilitation Report. Their inventory accounts for the largest discrepancy in the number of fuel rods and cans recovered. It would be possible to verify the cut ends inventory by examination of the bottom plug for positive identification of each cut end. Although the pieces would be sufficiently inactive to permit this, this activity wouldn't be necessarily appropriate to perform under the conditions of the retrieval operation. Two other extra fuel rods are assumed recovered which include Cooke's N Cooled Fuel Rod (P.I.R. #3802) and Lavigne's Flat Rod (P.I.R. #2549). No identification tags were recovered for either of these rods; however, it has been assumed that since these rods were present on the Gain/Loss report (X) that they were disposed at the same site. Recovered unidentified fuel rods have been assigned their identity based on physical size, weight and radiation fields which correlated with historical records of these two fuel rods. A "short rod" has been assigned the identity of Cooke's N Cooled Fuel Rod (P.I.R. #3802) and a fuel rod with relatively higher radiation fields has been assigned the identify of Lavigne's Flat Bar Rod (P.I.R. #2549). These two were included in the list of fuel rods requested for disposal in 1953, however not listed in the 1954 Rehabilitation Report.

The 1954 Rehabilitation Report discusses the disposal of the six damaged X-rod fuels, seen in Fig. 3, for which a request for disposal was made on October 8, 1953. Approval for the transfer of the six damaged X-rod fuel rods was indicated and records of the completed transfer can be found in the weekly reports of October 16 to 22, 1953 and October 23 to 29, 1953. During the 2005 site characterization, a number of visual observations led to conclusion that NRX X-rod fuels were present at the "Wood Box" location. Specifically the physical state of one fuel rod was consistent with the description of handling for X-rod #9770. As such the six damaged X-rod fuels were included in the suspect inventory within the historical assessment and identified for retrieval. The assumption during work planning was that identification would be verified by the recovery of identification tags or identifying marks on collars or cans. None of the identification tags recovered indicated that the six damaged X-rod fuels were among the fuel rods recovered. Additionally no identifying marks on collars or fuel cans were observed during the recovery. As such X-rods 7989-F, 9770, 5712, 5708, 5619, and 5538 are not listed in the inventory transferred to the modern storage facility in 2007. Assigning the unidentified fuel rods identities of the six X-rod fuels would result in discrepancies in the total inventory tally. Item 9 on Fig. 2 indicated that they were in a separate box, thus the location of the damaged X-rod fuels remains uncertain. Verification of their recovery in this retrieval would require detailed analysis of the recovered inventory. Confirmation may also arise as a result of additional site characterization of the entire "disposal grounds" (now referred to as waste management area) and the retrieval of other NRX accident associated burials at this location. Another possibility exists that these damaged fuel rods were later recovered from the disposal area for further research. These fuel rods were of considerable research interest due to their location within the NRX reactor at the time of the accident. The NRX accident presented a unique opportunity to investigate the properties of reactor fuel subjected to a partial meltdown.

The "Split Rod" was also unaccounted for in the recovery as detailed in the original suspect inventory presented in the historical assessment. Visual assessments performed during the 2005 site characterization, which was only a partial excavation, speculated the presence of the "Split Rod" adjacent to the "Wood Box" site. However, complete excavation in 2007 revealed no distinction between the two disposals due to the significant deterioration of the wood boxes. Additional cause for the identification of the Split Rod in 2005 was the low radiation fields observed from the partially exposed suspect fuel rod (0.7 mSv/hr). Radiation fields recorded during the retrieval operations in 2007 (Table II) are more accurate as they were measured fully exposed and removed from the interference of sand (shielding) and other fuel rods (collective dose rates). During the execution of the retrieval, a mangled aluminium can was recovered from the excavation site. Its discovery corroborates the recovery of fertile and fissionable material in Gain/Loss Report (Z), in which a fuel rod had been de-sheathed (i.e. removal of aluminium flow tube) and retrieved. Uncertainties in the identity of the Split Rod make verification of its location and history difficult.

CONCLUSIONS

The original suspect inventory compiled for the scope of the retrieval was primarily determined from a single reference (i.e. the 1954 Rehabilitation Report). The subsequent in-depth historical review not only resolved the unanticipated extra fuel rods and cans recovered but has also indicated a wider scope of potential inventory still buried in the "disposal grounds" (as inferred from Table II). During historical reviews secondary references are effective for verifying and supporting information from the primary references. If discrepancies between the historical records exist the inconsistency between the references should be analyzed to determine (to the best of one's ability) the potential impact of false information on the retrieval. When only primary references are relied upon as the single source of information quality information from potential secondary sources ends up overlooked.

In the end the project fully achieved the target objective to remove the inventory from the "Wood Box" and "Split Rod" burial site. The original assessment of the "Wood Box" inventory had indicated 19 fuel rods and cans (containing cut ends) would be present, including the "Split Rod" adjacent to the "Wood Box". However, a total of 32 fuel rods and cans (containing cut ends) were recovered and transferred to the modern fuel storage facility. The post-retrieval effort to resolve the inventory discrepancy had some success in assigning identities, however uncertainty remains. The fuel rods within this inventory are all very similar in nature, i.e. aluminium clad natural uranium metal with very low irradiation histories. The approximate content of plutonium present in the inventory is insignificant from a criticality or safeguards perspective, thus there are no safety implications as a result of the inability to conclusively identify each fuel rod or cut end. At this time the level of effort to disposition the discrepancies is satisfactory. There were no adverse effects on health, safety or the environment as a result of this project.

Recommendations

A recommendation from this experience has been to perform a general characterization of this specific waste management area in order to assess this site more comprehensively. Following the 1952 NRX accident, this site received all of the wastes from the cleanup activities. The 1952 NRX accident was the first reactor incident in the world. During these early stages of the nuclear industry, the focus after the accident was on refurbishment of NRX to regain operational status. The means and methods to achieve this resulted in minimal priority being placed on waste generation or environmental impact. The immediate environmental effects from the accident were evaluated and considered negligible; however the long-term cumulative influence and cost is undetermined. It was recommended that a complete review of the wastes generated, and discussion of the total affected lands as a result of this historic CRL event be undertaken, consistent with IAEA guidance for sites affects by past accidents [3]. Additionally the supplemental post-retrieval review indicated an inventory which may still be buried at the “disposal grounds” (i.e. Table II) which needs to be confirmed. Efforts have already begun to complete a historical summary and compilation of waste inventory for this specific waste management area. Field characterization will be required in the next couple of years to verify the historical assessment, assess the nature and condition of various burials or provide information on waste where no records exists. As a result of this retrieval experience, NLLP activities for waste management areas at CRL have evolved from focusing on individual burials to performing comprehensive characterizations and assessments for entire waste management areas.

REFERENCES

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Table II. Summary of historical records review to resolve inventory discrepancies after the retrieval operations in 2007. (NOTE: Italics indicates additional disposals from same source made on separate dates. Shaded entries indicate disposals that have been recovered.)

Date	Description of Disposal	Primary Reference	Secondary Reference	Details	Identification
21-Jan-53	1 control rod and 2 shut-off rods	Industrial Operation Sub-division Memo dated 21-Jan-1953	Disposal area drawing indicates location	Memo suggests that the rods be cut up and sent to the disposal area. It also mentions 2 empty cans from rods 7488 and 8594 be cut up and sent to disposal.	1 control rod and 2 shut-off rods
Aug 21 to Oct 8th, 1953	13-15 Cans of end pieces	Rehabilitation Progress report from August 21 to October 8th, 1953	Memo: Sample Rods Stored in Storage Bays in Fuel Rod Bays 11-Aug-1953; Disposal Slip started 22-Sep-1953;	A rod storage box was buried in the disposal area for storing material having received little irradiation. 13 cans containing ends from sheared X-rods were stored in this box. 11-Aug-1953 memo indicates 15 cans containing end plugs from X-rods.	Thirteen cans of end pieces.
22-Sep-53	*2 Rods*	*Disposal slip started 22-Sep-1953*	*See above*	*See above*	*See above*
23-Sep-53	*4 Rods*	*Disposal slip started 22-Sep-1953*	*See above*	*See above*	*See above*
25-Sep-53	*4 Rods*	*Disposal slip started 22-Sep-1953*	*See above*	*See above*	*See above*
02-Oct-53	*3 Rods*	*Disposal slip started 22-Sep-1953*	*See above*	*See above*	*See above*
08-Oct-53	3 Rods	8-Oct-1953 Memo: Sample Rods in Rod Bays	Group 3 rods mentioned again in 15-Dec-1953 memo (X-rods in Fuel Rod Bays) as requiring storage in disposal area	Request to store Group 3 rods in a separate area permanent storage in the disposal area. Group 3 rods contain more than 1 gm per 8 kg of U but cannot be processed due to shape limitations with transfer equipment.	Flat from NRU Loop #2, U Trans. From E-1, U Trans. From E-2
20-Oct-53	Rods in a wooden box (15 fuel rods and cans)	Disposal slip started September 22, 1953	Memo: Sample Rods in Fuel Rod Bays 8-Oct-1953; Weekly Progress Report from Oct. 16 to Oct. 22, 1953 for Fuel Rod Bays; Rehabilitation of Fuel Rod Bays, 30-Sep-1954	Group 1 rods containing less than 1 gm of Pu per 8 kg of U which is uneconomical to reprocess.	U.S. Stability Rod #1, Flats from NRU Loop #1
21-Oct-53	*Loose pieces*	*Disposal slip started 22-Sep-1953*	*See above*	*See above*	*Seven cans of end pieces*
22-Oct-53	*Rods*	*Disposal slip started 22-Sep-1953*	*See above*	*See above*	*6 damaged X-rods (5538, 5619, 5708, 5712, 9770, 7489)*
23-Oct-53	Rods (8 fuel rods)	Disposal slip started 22-Sep-1953	Memo: Sample Rods in Fuel Rod Bays 8-Oct-1953; Weekly Progress Report from Oct. to Oct. 22, 1953 for Fuel Rod Bays; Rehabilitation of Fuel Rod Bays, 30-Sep-1954	Group 1 rods containing less than 1 gm of Pu per 8 kg of U which is uneconomical to reprocess.	U.K. Slug Rod #2052, U.K. Stability Rod #5, U.K. Stability Rod 3913, Cook's Trans. Rod #2, Cook's Trans. Rod #3, Lavigne's flat bar rod 3394, Lavigne's U.Rod (M.J.L. #2/Dwg.1115-A)
26-Oct-53	*Rods*	*Disposal slip started 22-Sep-1953*	*See above*	*See above*	*See above*
15-Dec-53	1 Rod	15-Dec-1953 Memo: X-rods in Rod Bays that are not scheduled for delivery to the Extraction Branch		Discusses permission received to store Lavigne's Rod #2549 at disposal area because of low Pu content.	Lavigne's Flat Rod #2549
08-Apr-54	Numerous	April 4th Memo: Irradiated X-rods		Lists a number of damaged x-rods and sample rods, and cut-ends which are not expected to be transferred to the extraction branch that are still stored in Fuel Rod Bays (i.e. Groups B, E, F, G). These rods groups are not discussed in 1954 Rehabilitation Report.	Groups B, E, F, G